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(54) **CHARGE PUMPS WITH IMPROVED LATCHUP CHARACTERISTICS**

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(51) **Int. Cl.**

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**H02M 3/16** (2006.01)  
**H03L 7/089** (2006.01)  
**H02M 3/07** (2006.01)  
**H02M 1/00** (2006.01)

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CPC ..... **H03L 7/0895** (2013.01); **H02M 3/07** (2013.01); **H02M 3/073** (2013.01); **H02M 2003/071** (2013.01); **H02M 2001/0032** (2013.01); **Y02B 70/16** (2013.01)  
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(58) **Field of Classification Search**

None  
See application file for complete search history.

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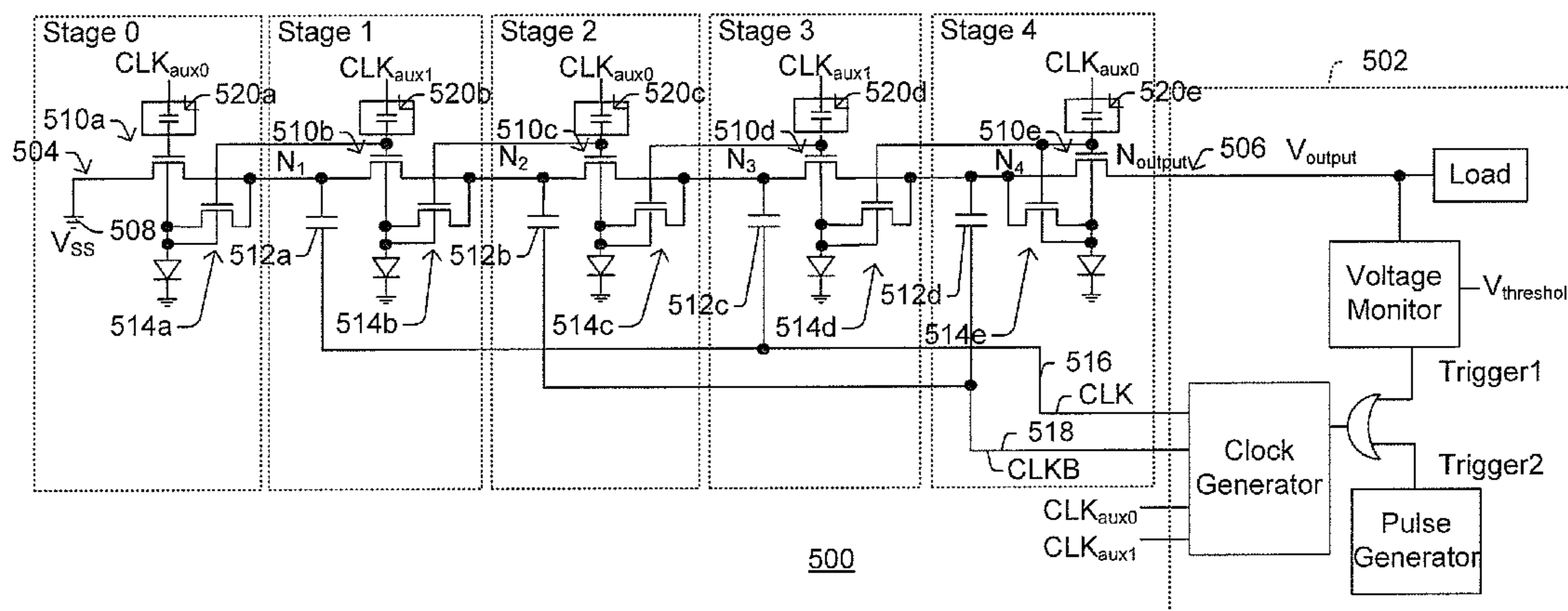
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(57) **ABSTRACT**

Some embodiments relate to charge pump regulators to selectively activate a charge pump based not only on the voltage output of the charge pump, but also on a series of wake-up pulses that are delivered at predetermined time intervals and which are delivered independently of the voltage output of the charge pump. Hence, these wake-up pulses prevent extended periods of time in which the charge pump is inactive, thereby helping to prevent latch-up in some situations.

**9 Claims, 5 Drawing Sheets**



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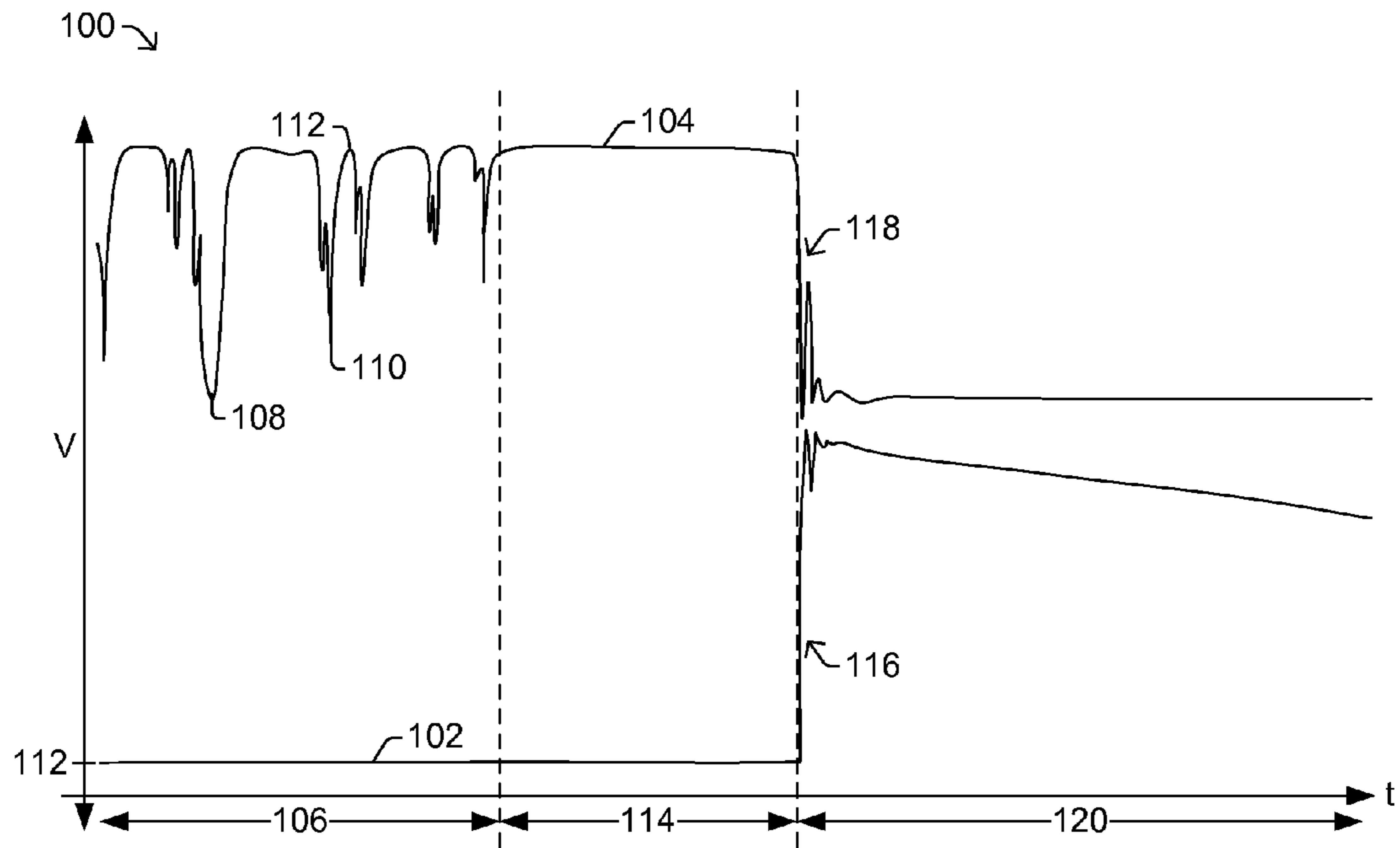
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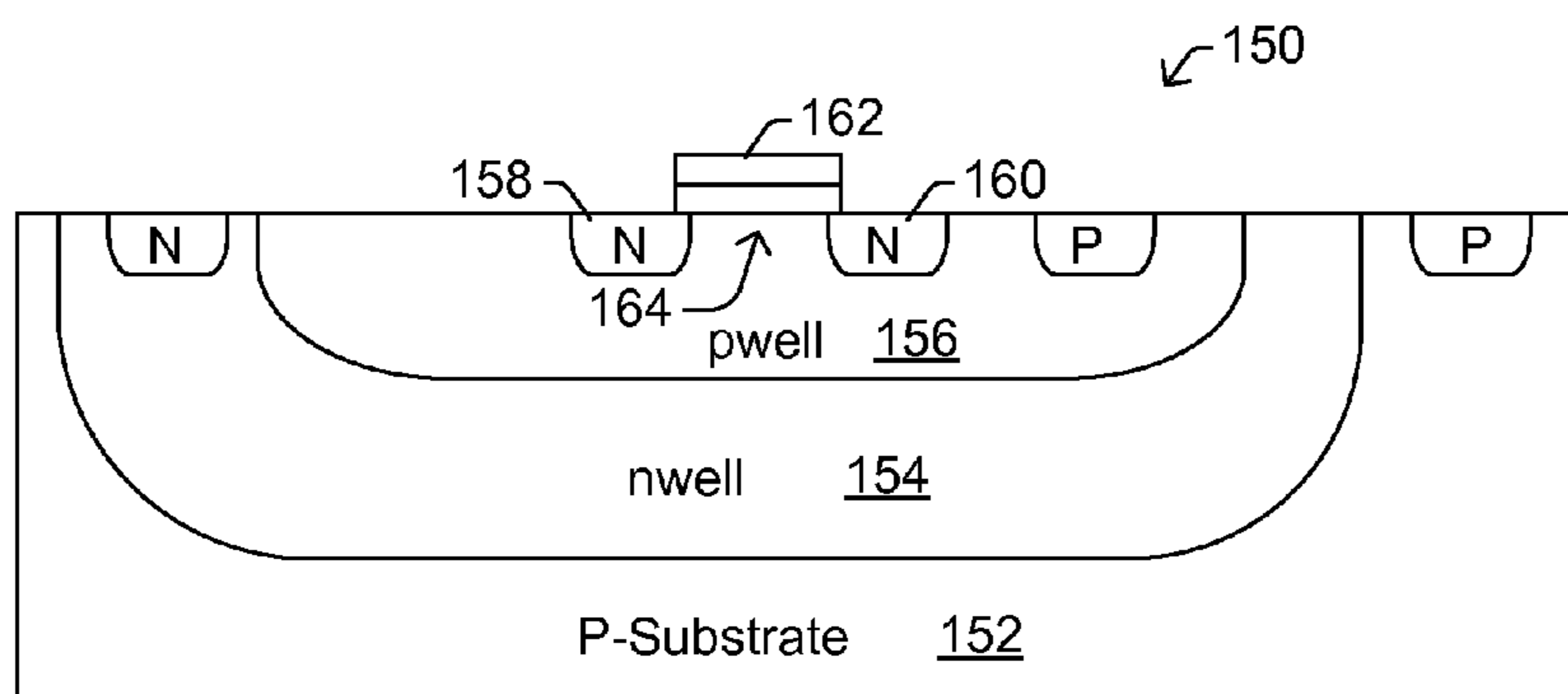
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**FIG. 1A**  
**(PRIOR ART)**



**FIG. 1B**

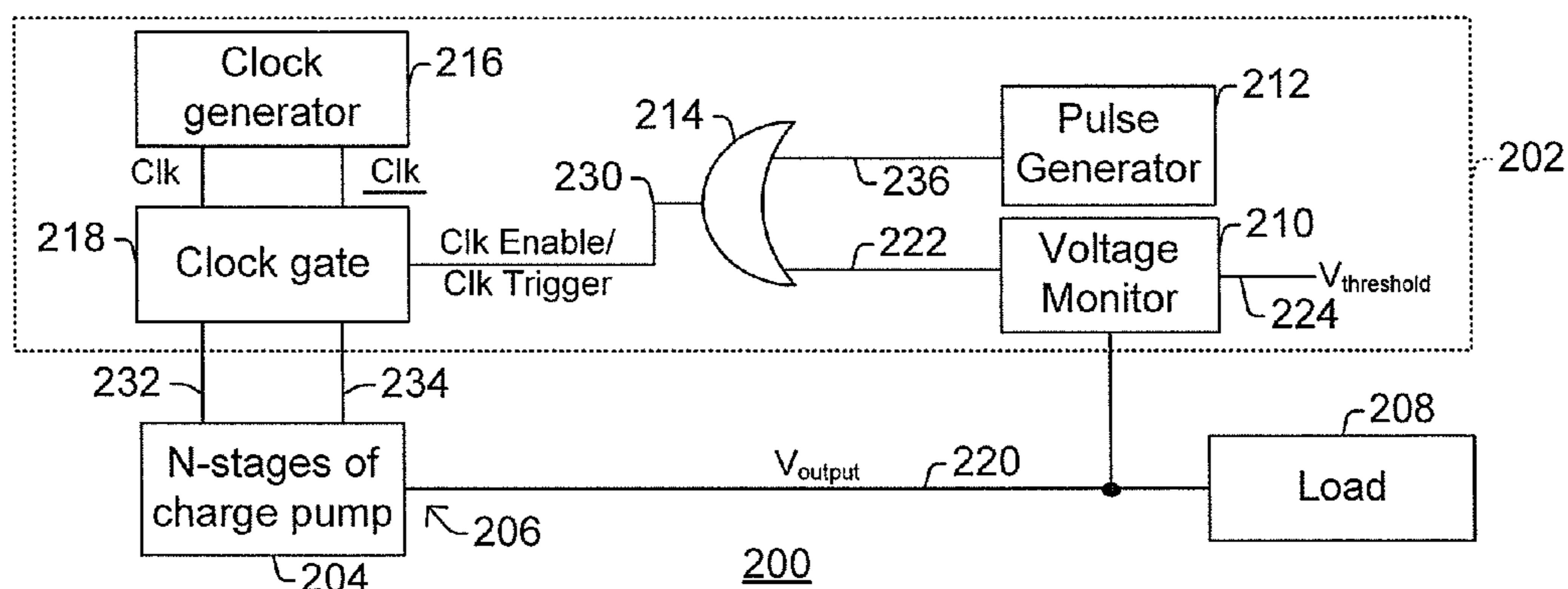


FIG. 2

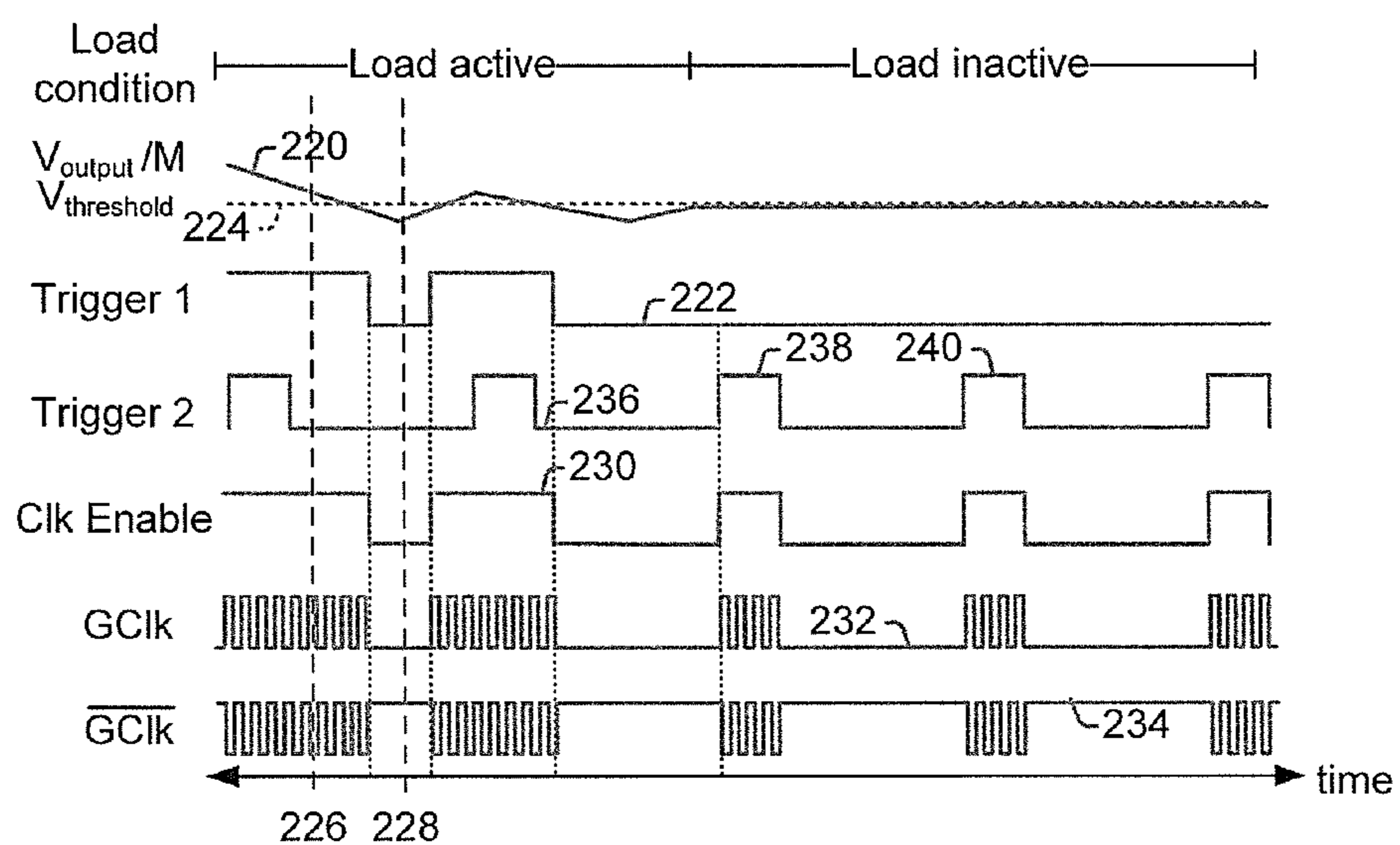


FIG. 3

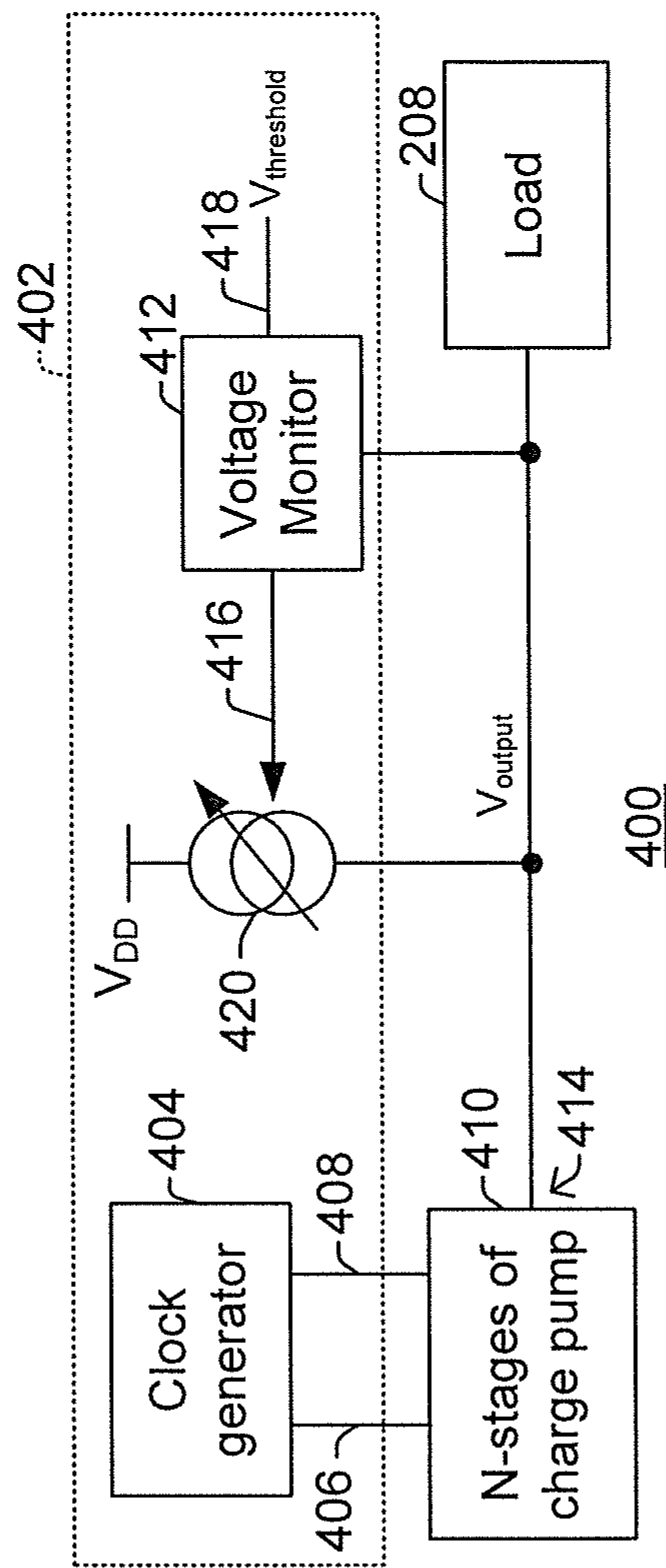


FIG. 4



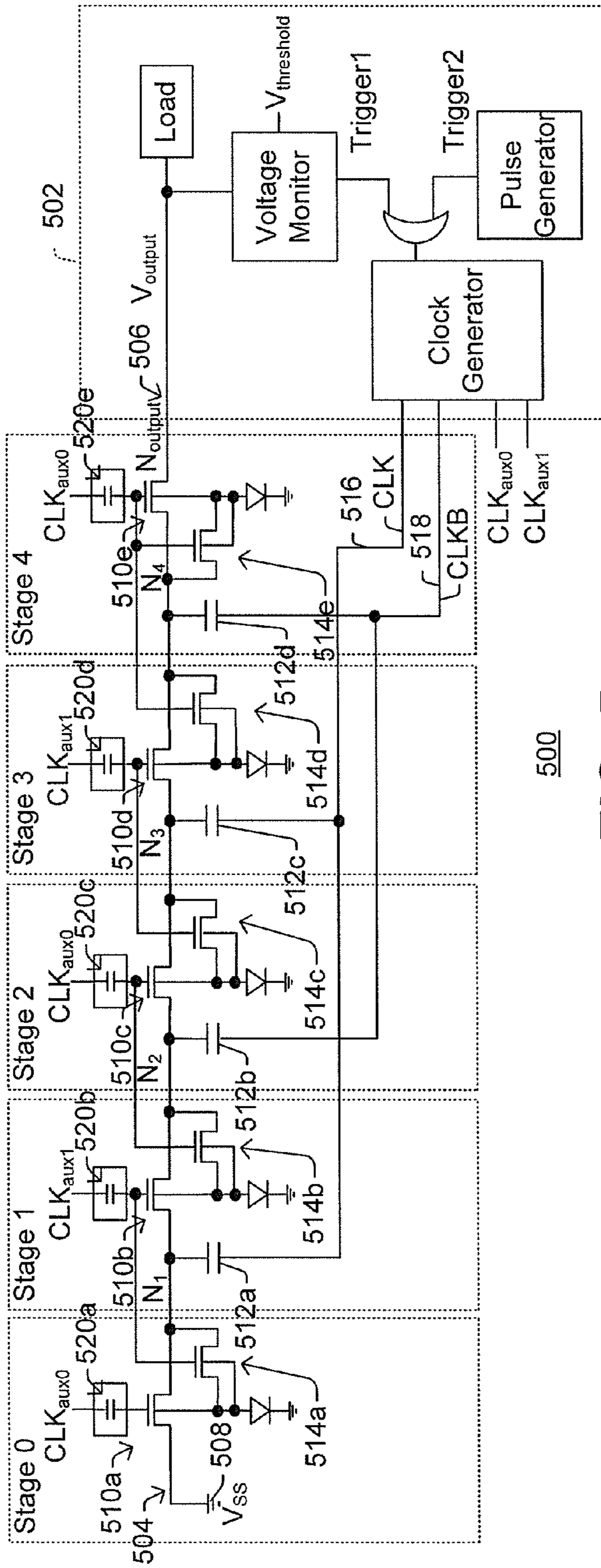


FIG. 5

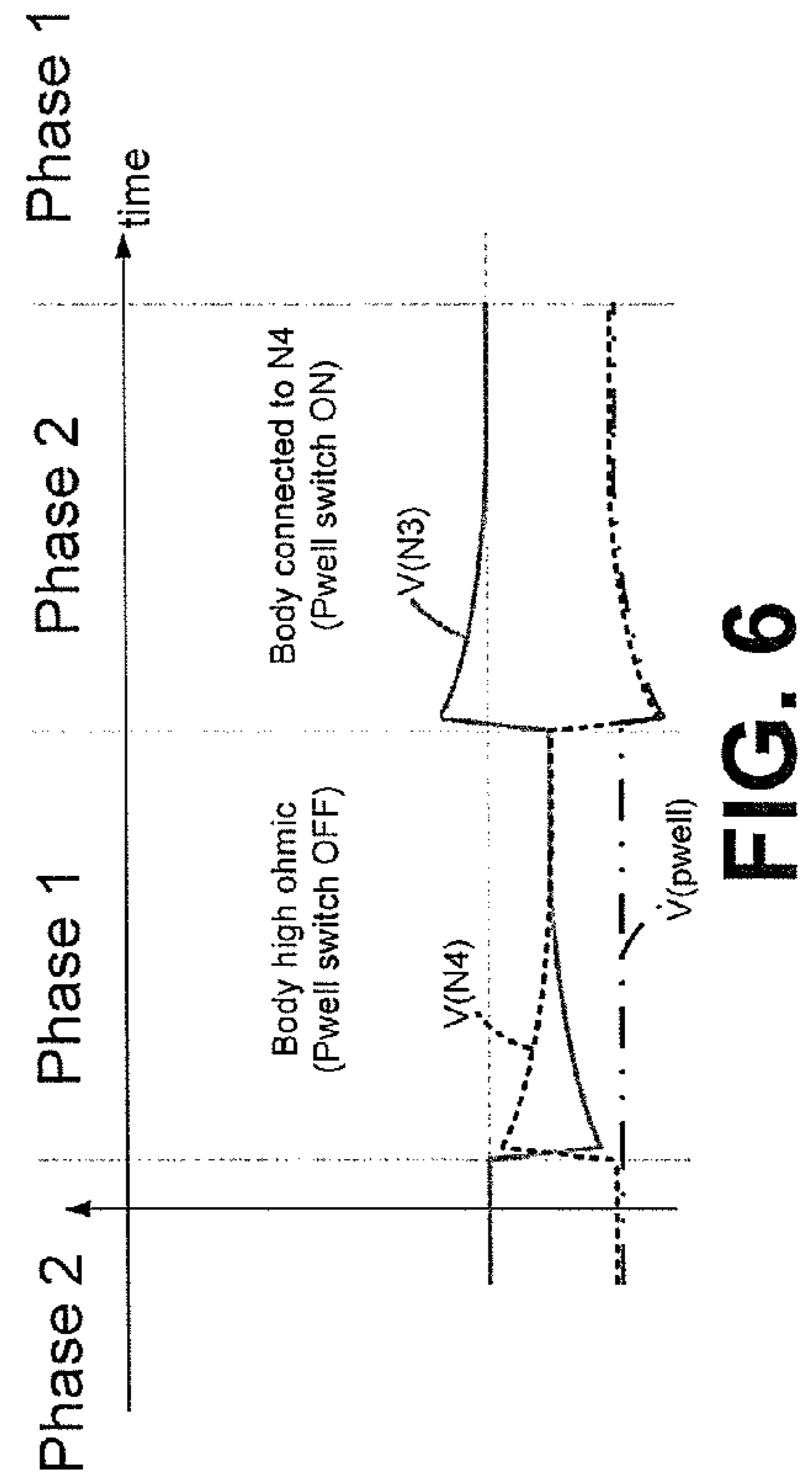


FIG. 6

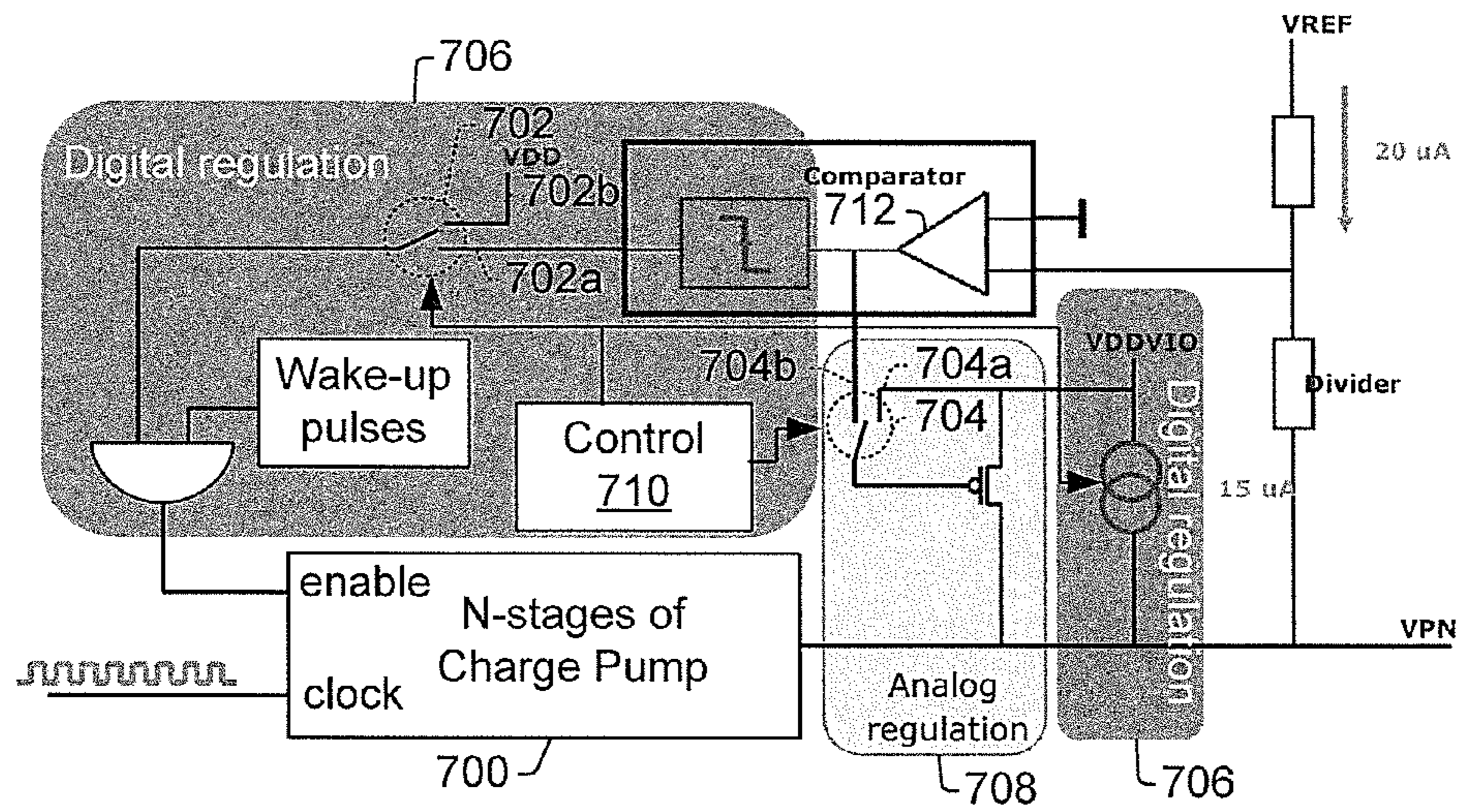


FIG. 7

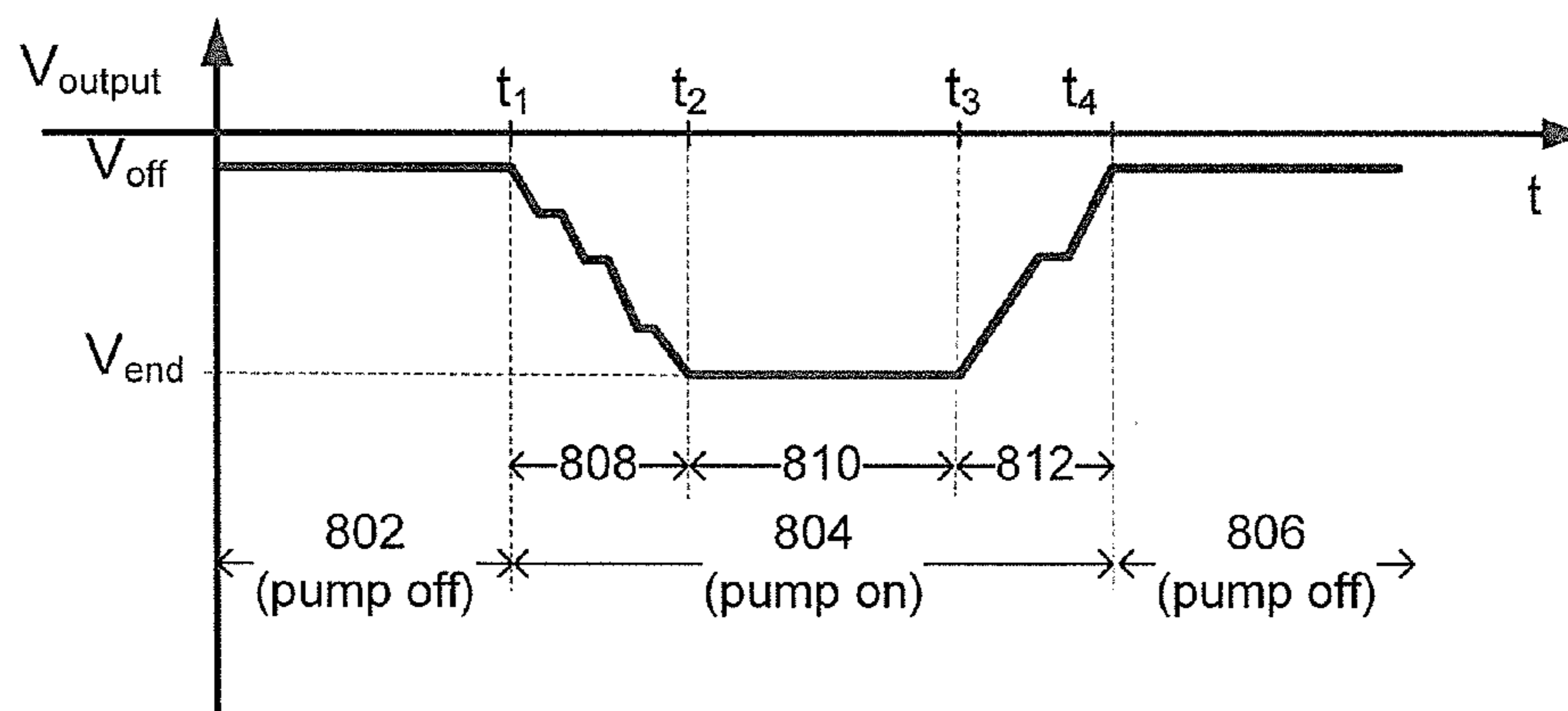


FIG. 8



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CHARGE PUMPS WITH IMPROVED  
LATCHUP CHARACTERISTICS

## REFERENCE TO RELATED APPLICATION

This Application is a Continuation In Part of U.S. application Ser. No. 12/956,225 filed on Nov. 30, 2010.

## BACKGROUND

Many electronic devices formed on an integrated circuit (IC), such as flash memory or electrically erasable programmable memory (EEPROM) for example, require voltage pulses with relatively large magnitudes for program and/or erase operations. In many electronic devices, these required voltage pulses are larger than a supply voltage powering the IC. For example, some flash memory chips often receive a supply voltage of about 5 volts on an external IC pin (many flash chips receive a supply voltage that is even lower than 5 volts), but require a “boosted” voltage of about -15 volts for erase operations.

Charge pumps are one type of circuit capable of delivering an output voltage with a “boosted” magnitude. To provide such a boosted output voltage, charge pumps include a number of switching elements arranged in series with one another, wherein charge transfer nodes are disposed between adjacent switching elements. Capacitors are coupled such that each capacitor has one plate coupled to a respective charge transfer node and has another plate coupled to one of at least two clock lines. Conventional charge pumps are regulated solely by monitoring an output voltage at an output node of the charge pump. In some negative charge pump implementations, for example, the charge pump is regulated so it continues to pump so long as the output voltage is higher than a target value. For example, if the target value is -16V, and the charge pump output is currently at -13V, the charge pump will continue to pump until the target value is reached. When the pump reaches the target voltage, the pump turns off. If the voltage output subsequently rises above the target voltage (e.g., rises to -10V), pumping commences again. Positive feedback continues in this manner such that the pump voltage output remains at or near the target voltage in a relatively constant manner.

Although such a regulation mechanism is adequate in some respects, difficulties can arise if the charge pump is inactive for an extended time period. For example, FIG. 1A shows a set of waveforms **100** that include an output voltage **102** provided by a conventional negative charge pump and a corresponding regulation signal **104**. When the regulation signal **104** is low (e.g., at **108**, **110**), the charge pump is active; and when the regulation signal is high (e.g., at **112**), the charge pump is inactive. Thus, during a first time interval **106** in which a load at the output of the charge pump is active (e.g., load is sourcing or sinking current), the charge pump is periodically activated (e.g., at **108** and **110**) to keep the output voltage **102** at or near a target value **112** (e.g., -16V). During a second time interval **114** in which the load is de-activated, the charge pump is continuously inactive and the output voltage continues to remain at or near the target value **112**. Thus, FIG. 1A’s chart illustrates proper charge pump functionality until the end of the second time interval **114**.

Notably, however, at the end of the second time interval **114**, there is an unexpected and rapid breakdown of the negative pump output at **116**. For example, at **116** the output voltage **102** can rapidly go from the target output voltage **112** (e.g., -16V) to a less negative output voltage (e.g., -3V). Although the regulation signal **104** is quickly activated at **118**

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to try to alleviate the rapid voltage breakdown, the charge pump is unable to quickly pump the output voltage **102** back down to the target output voltage **112**. This failure condition during time **120**, can be due to a bipolar effect (such as latch-up, for example).

To illustrate one particular example of how latch-up can arise in a manner consistent with FIG. 1A’s failure condition, FIG. 1B shows one switching element of a charge pump in the form of a triple well high voltage NMOS transistor **150**. The transistor **150** is formed on a p-type substrate **152**, and includes an n-type well **154**, a p-type well **156**, and n-type source/drain regions **158**, **160**. During normal operation, a gate voltage is selectively applied to a gate electrode **162** to form a conductive channel of charged carriers in a channel region **164** under the gate electrode **162**, thereby coupling the source/drain regions **158**, **160** to one another. However, when the charge pump is inactive for a long time period, the transistor **150** is correspondingly “open” throughout this time (i.e., gate voltage is continuously de-asserted throughout this long time period). Hence, the potential on the p-well **156** can begin to increase (e.g., by temperature dependent charging current of the reverse biased pn junction formed by pwell **156** and nwell **154**) ultimately leading to a forward bias being generated over pwell/source or pwell/drain junction and causing turn-on of the vertical npn transistor formed by n-source/**158**/pwell **156**/nwell **154** and/or n-drain **160**/pwell **156**/nwell **154** leading eventually to latch-up of the vertical 4-layer stack.

To remedy these shortcomings, the present disclosure provides improved charge pumps that limit failures due to latch-up.

## DESCRIPTION OF THE DRAWINGS

FIG. 1A is a waveform diagram that illustrates a failure condition of a conventional charge pump.

FIG. 1B shows an example of a HV-NMOS transistor that can be utilized as a switching element in a charge pump.

FIG. 2 is a block diagram of a charge pump that utilizes a digital regulator in accordance with some embodiments.

FIG. 3 is an example timing diagram consistent with FIG. 2’s embodiment.

FIG. 4 is a block diagram of a charge pump that utilizes an analog regulator in accordance with some embodiments.

FIG. 5 is a block diagram of a charge pump in accordance with some embodiments.

FIG. 6 is an example timing diagram consistent with FIG. 5’s embodiment.

FIG. 7 is a block diagram of a voltage regulation system where digital and analog regulation blocks regulate a voltage output provided by a charge pump.

FIG. 8 is a timing diagram illustrating an example of charge pump output voltage regulation.

## DETAILED DESCRIPTION

The claimed subject matter is now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the claimed subject matter. It may be evident, however, that the claimed subject matter may be practiced without these specific details.

Some embodiments of the present disclosure relate to improved regulators for charge pumps. Such regulators selectively activate a charge pump based not only on the voltage



output of the charge pump, but also on an series of wake-up pulses that are delivered at predetermined time intervals and which are delivered independently of the voltage output of the charge pump. Hence, these wake-up pulses prevent extended periods of time in which the charge pump is inactive (see e.g., FIG. 1A's extended period of time 114 in which the charge pump is inactive), thereby helping to prevent latch-up in some situations.

FIG. 2 illustrates a charge pump 200 that includes a regulator 202 in accordance with some embodiments. The charge pump 200 includes a number (N) of charge pump stages 204, wherein the last charge pump stage includes a charge pump output 206 operably coupled to a load 208 (e.g., flash memory cell). Each of the charge pump stages typically receives a gated clock signal 232 and an inverted version of the gated clock signal 234. These clock signals collectively establish different clock phases for properly biasing capacitors and transistors in the N-stage charge pump 204, thereby "pumping" charge through consecutive stages of the charge pump to deliver a desired output voltage  $V_{output}$  to the load 208 via the charge pump output 206.

The regulator 202 includes a voltage monitor 210, a pulse generator 212, a logical-OR gate 214, a clock generator 216, and a clock gating module 218, which are operably coupled as shown. Referring now to FIGS. 2-3 collectively, operation of the regulator 202 and charge pump 200 are discussed. During operation, the voltage monitor 210 monitors an output voltage 220 at the charge pump output 206. The voltage monitor 210 then selectively activates a first trigger signal 222 based on whether the output voltage 220 (or a fraction of the output voltage  $220 = V_{output}/M$ ) has a predetermined relationship with a predetermined voltage threshold 224. For example, at time 226 the output voltage 220 (or a fraction of the output voltage  $V_{output}/M$ ) is higher than the voltage threshold 224, so the first trigger signal 222 is activated. In contrast, at time 228, the output voltage 220 (or a fraction thereof) is less than (more negative than) the predetermined voltage threshold 224, so the first trigger signal 222 is deactivated. Due to the logical-OR gate 214, the first trigger signal 222 correspondingly activates the clock enable signal 230, which selectively provides the gated clock signal 232 and inverse gated clock signal 234 to the N-stage charge pump 204. When active, these clock signals 232, 234 control the N charge pump stages 204 so as to incrementally transfer charge through consecutive pump stages in a manner that regulates the voltage on the charge pump output 206 towards the predetermined voltage threshold 224.

To prevent the N charge pump stages 204 from being de-activated for extended periods of time (e.g., which as shown in FIG. 1A can lead to latch-up), the pulse generator 212 generates a second trigger signal 236 having a series of wake-up pulses (e.g., 238, 240) that are spaced at predetermined time intervals. Although the wake-up pulses are shown as occurring at regularly spaced time intervals, in other embodiments the time intervals can be non-regularly spaced or can be spaced in other ways (e.g., random or pseudo-randomly). Due to the logical-OR gate 214, the second trigger signal 236 also triggers the clock enable signal 230, and ultimately activates the N charge pump stages 204 via the gated clock signals 232, 234. Consequently, the regulator 202 helps to reduce the likelihood of latch-up compared to conventional charge pumps, in particular due to the pulse generator 212.

Although FIG. 3 shows one example of a set of waveforms consistent with FIG. 2's embodiment, it will be appreciated that these waveforms are merely an example of sample functionality to aid in the reader's understanding, and are not

limiting in any way. For example, in some other implementations the polarities of the signals could be inverted, provided that corresponding changes are made to charge pump (e.g., replace the logical-OR gate with a logical-NAND gate or make other changes in the various components). A myriad of other changes could also be made.

FIG. 4 shows another embodiment of a charge pump 400 that includes a regulator in accordance with some embodiments. In contrast to FIG. 2's charge pump 200, which uses a digital regulator, FIG. 4's charge pump 400 uses an analog regulator 402. The analog regulator 402 includes a clock generator 404 to provide a clock signal 406 and an inverted clock signal 408 to the N charge pump stages 410, thereby facilitating incremental charge transfer along a charge transfer path therein. A voltage monitor 412 monitors an output voltage at the charge pump output 414, and continuously adjusts a voltage level of a control signal 416 based on whether the monitored voltage has a predetermined relationship with a predetermined voltage threshold 418. A variable current source 420 is coupled to the charge pump output 414 and adapted to adjust a current sourced to or sunk from the charge pump output 414 based on the voltage level of the control signal 416.

It will be appreciated that this charge pump 400 typically tends to consume more power than charge pump 200, largely because the clock signals 406, 408 are continuously provided to the N charge pump stages 410. Because there is no clock gating module or clock enable, the pump stage 410 are on for a significant amount of time and the output voltage is regulated by varying the variable current source 420 coupled to the pump output 414. Hence, in many applications where power might be an issue such as mobile applications, charge pump 200, which uses digital regulation, is preferred over charge pump 400, which uses analog regulation, although both are workable solutions in many regards.

Combinations of digital and analog regulation can be used in some embodiments. For example, FIG. 7 shows an example where switching elements 702, 704 promote either digital regulation or analog regulation for a charge pump 700 at a given time. For example, if switching element 702 is in position 702a and switching element 704 is in position 704a, then digital regulation block 706 is used to regulate the charge pump 700. In digital regulation, the comparator 712 provides a control signal that selectively enables the charge pump and wake up pulses intermittently cause the charge pump to pump. A variable current source can sink or source current at the output of charge pump to keep the charge due to the wake up pulses from undesirably changing the output voltage. Alternatively, if switching element 702 is in position 702b and switching element 704 is in position 704b, then analog regulation block 708 is used to regulate the charge pump 700. In particular, the PMOS transistor in analog regulation block 708 can continuously provide charge to the output of the VPN pump. If the charge provided is higher than the pump is able to sink the output node is increasing. In case the PMOS deliver lower charge than the pump current the output node is lowered. Thus, to keep a desired voltage level VPN the charging current is continuously regulated by the comparator based on the voltage on node VPN, thereby enabling analog regulation of charge pump 700. Compared to analog regulation, digital regulation tends to be lower power. However, due to the fact that digital regulation changes state only at discrete time intervals (e.g., clock periods), it is also less accurate than analog regulation which continuously reflects the state of the system. A control block controls 710 provides control signals



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to set the state of the switches **702**, **704** depending whether predetermined voltage conditions and/or timing conditions are met.

As shown in FIG. **8**, a charge pump can vary between being in an ON state and an OFF state depending on how its voltage output compares to a predetermined voltage threshold ( $V_{off}$ ) over time. For example, at **802** and **806** the pump is in the off state and the voltage output (e.g., VPN in FIG. **7**) is at a predetermined voltage threshold ( $V_{off}$ ), which represents the discharge level for normal device operation (e.g., to read a non-volatile memory cell or program the non-volatile memory cell). However, during **804** a lower output voltage level is required (e.g. to erase a cell in a nonvolatile memory). Typically, this lower voltage operation **804** can be divided into three phases: ramping phase at beginning (**808**) (e.g. charging of the path to the target memory cell), steady ON state (**810**) (performing the Erase operation on the memory cell), and ramping phase at the end (**812**) (to prepare for normal operation like read again). Due to the various benefits of analog or digital regulation, analog or digital operation might be preferred depending on the phase. For instance a proper setting for a negative charge pump might be to run phases **808** and **810** in a digital regulation mode due to power reasons, while phase **812** might be run in the analog regulation mode. In phase **812** the pump output and the connected nodes should be discharged in a fast and latch-up free manner. Power is not a primary issue during phase **812** due to relatively fast discharge times. Hence, an analog regulation might be preferred during **812** because the pump is in a continuous operating mode and does not pause. In case a low output voltage ripple is required during phase **810**, an analog regulation (for high precision output voltage) might be more beneficial than a digital regulation. In this case phase **808** should run in digital regulation and phase **810** and phase **812** in an analog mode.

FIG. **5** shows an example of a negative charge pump **500** that includes four pump stages. It will be appreciated that charge pumps in accordance with this disclosure can have any number of charge pump stages, including less than four or more than four. For purposes of illustration the negative charge pump **500** is shown as coupled to a digital regulator **502**, although other embodiments could include an analog regulator in place thereof (e.g., regulator **402** in FIG. **4**).

The charge pump **500** includes a charge transfer path **504** extending between a pump output **506** and a DC supply terminal **508** (e.g., ground/ $V_{ss}$ ). Charge transfer transistors **510a**, **510b**, **510c**, **510d**, **510e** are arranged in series along the charge transfer path **504**, wherein charge transfer nodes N1, N2, N3, N4 are disposed between adjacent charge transfer transistors. Capacitors **512a**, **512b**, **512c**, **512d** have respective first plates coupled to the charge transfer nodes N1, N2, N3, N4, respectively, and have respective second plates coupled to one of at least two clock lines **516**, **518**. The clock lines **516**, **518** provide different clock signals that collectively establish different clock phases for properly biasing the capacitors and transistors to facilitate charge flow. FIG. **5** shows two clock signals, namely a clock signal (CLK) on the first clock line **516** and an inverted version of the clock signal (CLKB) on the second clock line **518**. Auxiliary clocks  $CLK_{Aux0}$ ,  $CLK_{Aux1}$  are coupled to auxiliary capacitors **520a**-**520e** as shown, and are used to boost charge transfer transistors **510a**-**510e**, respectively, into on/off states.

During operation, alternating charge transfer transistors switch in coordinated fashion under the control of the clock signals to incrementally “sweep” or “pump” charge along the charge transfer path **504**. In particular, the charge is pumped down the charge transfer path **504** such that the charge is at a

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first potential at one end of the charge transfer path and is at a second, different potential at the other end of the charge transfer path.

For example, during a first clock phase in which CLK is low and CLKB is high, the charge transfer transistors **510b**, **510d** are closed, thereby inducing charge transfer from N2 to N1 (and driving the voltage of N1 to be less than the voltage of N2) and similarly inducing charge transfer from N4 to N3 (and driving the voltage of N3 to be less than the voltage of N4). During a second clock phase in which CLK is high and CLKB is low; charge transfer transistors **510a**, **510c**, and **510e** are closed and inducing corresponding charge flow.

To limit body bias effects and to help prevent latch-up, a series of body bias transistors **514a**, **514b**, **514c**, **514d**, **514e** are also included in the charge pump. A first body bias transistor **514d** has a source terminal coupled to a first charge transfer node N4 and has a drain that is coupled to a body of a first charge transfer transistor **510d**. The first body bias transistor **514d** is operable to selectively couple the first charge transfer node N4 to the body of the first charge transistor **510d** based on the first and second trigger signals, via the auxiliary clocks  $CLK_{Aux0}$ ,  $CLK_{Aux1}$ .

Similarly, a second body bias transistor **514e** has a source terminal coupled to the first charge transfer node N4 and has a drain terminal coupled to a body of a second charge transfer transistor **510e**. The second body bias transistor **514e** is operable to selectively couple the first charge transfer node N4 to the body of the second charge transistor **510e** based on the first and second trigger signals via the auxiliary clocks  $CLK_{Aux0}$ ,  $CLK_{Aux1}$ .

In many embodiments, the first charge transfer node N4 is coupled to the bodies of the first and second charge transfer transistors **510d**, **510e** during a clock phase in which the first charge transfer node N4 is at a minimum voltage potential experienced during charge pumping. Thus, in FIG. **6**, for example, body bias transistors **514d**, **514e** couple the bodies of the first and second charge transfer transistors **510d**, **510e** to node N4 during the phase 2, because this is the time period during which node N4 is at the minimum voltage potential during charge pumping. This helps to prevent forward bias from a well of the charge transfer transistors with respect to source/drain regions of the charge transfer transistors, which also helps to limit latch-up in many respects.

Although the disclosure has been shown and described with respect to one or more implementations, equivalent alterations and modifications will occur to others skilled in the art based upon a reading and understanding of this specification and the annexed drawings. For example, it will be appreciated that identifiers such as “first” and “second” do not imply any type of ordering or placement with respect to other elements; but rather “first” and “second” and other similar identifiers are just generic identifiers. In addition, it will be appreciated that the term “coupled” includes direct and indirect coupling. The disclosure includes all such modifications and alterations and is limited only by the scope of the following claims. In particular regard to the various functions performed by the above described components (e.g., elements and/or resources), the terms used to describe such components are intended to correspond, unless otherwise indicated, to any component which performs the specified function of the described component (e.g., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations of the disclosure. In addition, while a particular feature of the disclosure may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other



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features of the other implementations as may be desired and advantageous for any given or particular application. In addition, the articles “a” and “an” as used in this application and the appended claims are to be construed to mean “one or more”.

Furthermore, to the extent that the terms “includes”, “having”, “has”, “with”, or variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term “comprising.”

What is claimed is:

**1.** A charge pump, comprising:

a plurality of charge transfer transistors arranged in series along a charge transfer path extending between an output of the charge pump and a supply terminal, wherein a first charge transfer node is arranged between first and second charge transfer transistors that are adjacent to one another within the plurality of charge transfer transistors;

a first capacitor having a first plate terminal coupled to the first charge transfer node and having a second plate terminal operably coupled to a first clock line; and

a first body bias transistor having a source terminal coupled to the first charge transfer node and having a drain terminal coupled to a body of the first charge transfer transistor, wherein the first body bias transistor is operable to selectively couple the first charge transfer node to the body of the first charge transfer transistor based on both an output voltage at the output of the charge pump and a series of wake-up pulses, wherein the wake-up pulses are spaced at predetermined time intervals that are independent of the output voltage.

**2.** The charge pump of claim **1**, wherein the first charge transfer node is coupled to the body of the first charge transfer transistor during a clock phase in which the first charge transfer node is at a minimum voltage potential experienced during charge pumping.

**3.** The charge pump of claim **1**, further comprising a regulator that comprises:

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a voltage monitor to monitor the output voltage and selectively assert a first trigger signal based on whether the output voltage has a predetermined relationship with a predetermined voltage threshold;

a pulse generator to generate a second trigger signal by providing the series of wake-up pulses spaced at the predetermined time intervals; and

a clock module to selectively provide a clock signal based on both the first trigger signal and the second trigger signal.

**4.** The charge pump of claim **1**, further comprising a second body bias transistor having a source terminal coupled to the first charge transfer node and having a drain terminal coupled to a body of the second charge transfer transistor.

**5.** The charge pump of claim **4**, wherein the second body bias transistor is operable to selectively couple the first charge transfer node to the body of the second charge transfer transistor based on both the output voltage and the series of wake-up pulses.

**6.** The charge pump of claim **1**, further comprising:

a second body bias transistor having a source terminal coupled to a second charge transfer node that differs from the first charge transfer node, and having a drain terminal coupled to a body of the second charge transfer transistor.

**7.** The charge pump of claim **6**, wherein the second body bias transistor is operable to selectively couple the second charge transfer node to the body of the second charge transfer transistor based on both the output voltage and the series of wake-up pulses.

**8.** The charge pump of claim **1**, wherein the first body bias transistor has the source terminal continuously coupled to the first charge transfer node.

**9.** The charge pump of claim **1**, wherein the first body bias transistor is a metal oxide semiconductor field effect transistor.

\* \* \* \* \*